NASA TECHNICAL
MEMORANDUM

NASA TM X-53537

November 14, 1966

NASA TM X-53537

FACILITY FORM 602

N67 16541
(ACCESSION NUMBER)

(THRU)

37
(PAGES)

1
(CODE)

TMX-53537
(NASA CR OR TMX OR AD NUMBER)

15
(CATEGORY)

A STUDY OF THE EFFECTS OF VARIOUS HEAT INPUT RATES ON T-1A STEEL WELDS

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GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

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ABSTRACT

An experimental program was executed to evaluate the effects of welding restrained butt-joints of T-1 and T-1A steel plate under conditions involving variations of weld heat input rates, plate thickness and weld groove design. Tensile tests, hardness measurements, and bend tests were made for each set of conditions. Test results show that close control is necessary to prevent overheating these steels during welding. Considerable strength and toughness losses are incurred through overheating.

Production controls and preproduction development necessary to assure weldment integrity are discussed.

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PROPULSION & VEHICLE ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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SUMMARY

The effects of welding highly restrained butt-joints of T-1 and T-1A structural steel plate were investigated under conditions involving variations of welding heat input rates, plate thickness and weld groove design. Tensile tests, hardness measurements, bend tests, and extensive metallurgical analyses of the test welds were made. It was determined that excessive welding heat has a marked effect on the mechanical properties of the welds in that the strength and ductility are drastically reduced. In general, the welding procedures recommended by the alloy manufacturer are reliable, but must be adhered to very closely.

The variation of test results indicates that the production controls needed to insure high weldment integrity must include extensive preproduction development of welding procedures. Customary margins of latitude in welding ordinary construction steels are too wide for application to these heat-sensitive steels.

INTRODUCTION

Widespread weld-fabrication of T-1 and T-1A steels by a comparably wide variation in technical competence of fabricators has produced apparent contradictions and confusion regarding their use. Much of the information reported in the literature has been pertinent, but some has been challenged by practical fabricators. The unusual requirements for reliable, quenched and tempered structural steel weldments present problems which warrant recognition and cautious handling. The potential advantages of these steels relative to meeting aerospace objectives have emphasized the need for dependable, working knowledge of them, especially with regard to the reliability of weldments. The primary purposes of this investigation were to resolve some of these questions by emphasizing and correlating the technology of these steels pertinent to practical production weld-fabrication.

*Chrysler Corporation, Space Division

The program was designed to investigate 16 combinations comprised of two variations in each of four significant criteria as follows:

1. Grades of steel: T-1 and T-1A

2. Plate thickness: 1/2-inch and 1 inch

3. Weld groove design: U and V

4. Welding heat intensity: *Low and high

*(Related to manufacturer's recommendations)

All weldments were designed to represent the following:

1. Plane butt-joints: flat position

2. Maximum possible restraint

3. Manual arc welding with coated electrodes

4. Malpractices in welding these steels with both insufficient and excessive heat.

This investigation was approached from the following viewpoints:

First, the main interest in these steels is based on their impressive potential for efficient engineering design in welded structures. Enthusiasm for them has suffered substantial restraint due to fears of failure based largely upon unfamiliarity and suspicion inherent to using such a relatively new type of structural steel. The frequency and substance of reports indicating disappointment with the weldability of these steels have probably distorted the truth. However, this indicates that minimum standards of welding control and discipline are more critical in this class of steel than in conventional structural steels.

Second, conditions corresponding to production weldment circumstances were considered. The program was based on the use of good commercial welding practices which allowed a certain amount of latitude to welders fabricating the test weldments, although sound welding techniques were always used.

Third, welding heat input rate was considered the primary control parameter in the program. Under predetermined conditions of interpass temperature, arc energy and welding speed, the significant problem to resolve was that of maintaining uniformity quite comparable to machine welding. With this problem resolved, necessary control could be exercised concurrently with reasonably close simulation of production conditions.

EXPERIMENTAL

Preparation of Weldments

Materials and equipment. - The plate material and significant equipment and supplies used were as follows:

1. Commercial warehouse plates were prepared according to the following schedule:

   a. T-1 steel, 1/2 inch x 10 inches x 30 inches

   b. T-1 steel, 1 inch x 10 inches x 30 inches

   c. T-1A steel, 1/2 inch x 10 inches x 30 inches

   d. T-1A steel, 1 inch x 10 inches x 30 inches

2. Commercial electrodes of classes E-7018 and E-11018 were used. All electrodes were baked at 427°C (800°F) for one hour and subsequently maintained between 121°C to 149°C (250°F to 300°F) until removed from the storing oven for use.

3. The welding power supply was an Airco D-C rectifier.

4. 93°C to 316°C (200°F to 600°F) temperature indicating crayons (Tempilstiks) were used to indicate plate control temperatures.

5. A weldment restraining fixture was fabricated from T-1 steel bars (cut from plate) 1-inch thick by 4-inches wide. They were fillet-welded into a box frame 30 inches x 22 inches x 4 inches using two 30-inch longitudinal bars and four 20-inch inside cross members flush at the ends and equally spaced in the longitudinal direction.

Weld joint design and weldment requirements. - The following were requirements established to provide the sixteen weldment combinations prescribed in the scope:

1. High and low transverse weld stresses were simulated by both wide and narrow weld groove designs, respectively, in each combination of material grade and thickness by preparing plates according to FIG 1.

2. Rigidity was provided by placing a large fillet weld along the entire length of each plate (parallel to the weld joint) at the juncture of the rigid backing frame.

This operation was accomplished after depositing the initial root pass in the specimen weldment to hold the plates in proper position.

3. Production malpractices of both insufficient as well as excessive welding heat input most frequently associated with T-1 and T-1A weldment failures were simulated.

4. Good welding practices were observed in all other details not preempted by the above requirements.

Welding procedure and technique. - Prior to actual welding, it was necessary to determine the handling characteristics of the electrodes with the power supply to be used. Several electrodes were deposited and correlation between the welding current giving the smoothest arc action, low spatter, and optimum slag control was observed. The current giving the most satisfactory control was thus identified for each electrode size and type to be used. Voltage was determined to be uniformly within the range of 22 to 23 volts, almost regardless of arc length. Accurately calibrated meters for both voltage and current were used for these determinations, and the corresponding machine settings were established. These optimum data, correlated with desired heat input rates, were then used to calculate required welding speed. With chalk-marked intervals for guides, trial weld beads were deposited to establish welder orientation in electrode manipulation, bead width, and slag control to produce the predetermined welding heat input rates. This procedure established the length of weld pass deposited from each electrode, when consumed to a 2-inch stub, as the significant variable related to required heat input rates. The welder then used the same weld bead length per electrode, laid out along the weld groove, and the corresponding requirements summarized in Table I to assure desired heat input rate during welding.

Employing the welding conditions presented in Table I for the corresponding weldment requirements,the following procedure was implemented:

1. Test plates were tacked to the backing frame.

2. Frame and plates were preheated uniformly to 93°C (200°F) minimum temperature.

3. The initial root pass was deposited with E-7018 electrodes.

4. Restraining fillet welds were deposited to secure the test plates rigidly to the backing frame; 1/4-inch minimum fillet size was used for 1/2-inch plate and a 1/2-inch minimum fillet size was used for 1-inch plates.

5. The weld length to be deposited by each electrode was selected according to Table I with chalk lines transverse to the weld axis used as a guide to the correct weld heat input rate.

6. The joint was completed by welding with E-11018 electrodes as follows:

a. One stringer pass was deposited from the end toward center.

b. Each bead was completed by back-step welding between succeeding intervals (as described in 5 above). This welding sequence was continued until the joint was completed.

c. Welding conformed to the voltage, current and electrode size specified for each weldment according to Table I.

d. Prior to making each pass, the temperature of the plate was restricted to 149°C (300°F) maximum within the increment to be welded. A Tempilstik was used for control.

e. Slag was removed from each preceding pass to assure sound weld metal in each succeeding pass.

f. Electrode discipline was maintained to assure the following:

(1) Atmospheric exposure was limited to 30 minutes after removal from the electrode holding oven [(maintained between 121°C to 149°C (250°F to 300°F)].

(2) All defective electrodes or any remainder of an electrode not consumed after initial arc starting were discarded.

g. The arc for each electrode was established by striking approximately one inch ahead of the intended starting point, then removing the arc to the starting point of the pass, followed by deposition of weld metal in the intended manner remelting the arc strike area.

h. The shortest possible arc length was maintained consistent with good slag control and continuity of welding.

i. The final weld layer was deposited with minimum reinforcement and at least flush with the plate surface.

j. The completed plate was removed from the backing frame, the weld root was arc-air gouged and ground to sound metal. After determining that the plate was at 93°C (200°F) minimum temperature, the backing weld was deposited at least flush with the plate surface.

TEST RESULTS

Method of Presentation

Data sheets designed with uniform organization and arrangement of information are used to summarize all test results for each weldment (FIG 2 through 17). These data sheets contain the following information:

1. DPH hardness traverses related to a specific weld cross section.

2. Test results obtained from tensile and side bend specimens removed from a weldment made under specific conditions.

3. Photographs of the tested tensile and side bend specimens.

Hardness impressions were made on the specimens with uniform spacing of 0.020-inch. Hardness plots have the weld-base metal interfaces indicated. Face weld plots are discontinuous because of the relative uniformity of hardness in areas not recorded.

Evaluation Criteria and Predominant Failure Patterns

Guided side bend tests. - Guided side bend tests are conventionally used to indicate soundness in welds. They were so employed in this study in addition to X-ray examination. Side bend testing stresses weld face and root areas equally; and by interrupting bend tests at initiation of fracture, the angle of bend and failure location were used as indications of stress raiser effects in these specimens. There was a high incidence of failure initiation in the HAZ of the backing weld in these bend tests. Attempts to correlate bend test results with material grade, heat input rate, or similar criteria were inconclusive.

Tensile tests, hardness, and toughness. - Tensile failure occurred predominantly in the weld HAZ adjacent to the line-of-fusion and usually initiated in the backing weld of the root side. Toughness is the critical evaluation criterion for steels such as T-1 and T-1A. The Charpy V-notch impact test, generally accepted for toughness evaluation of wrought steel, has not been found effective when applied to weldments. The weld HAZ contains a wide range of microstructures, and consequently a comparable variation in mechanical properties, instead of the relatively uniform condition of wrought material. Within this zone there is a narrow, critical area of minimum toughness. It has been found to be impossible to locate the Charpy specimen notch consistently at this critical location and impact test results are, therefore, inconsistent and unreliable. Unqualified use of the hardness test does not provide reliable correlation with toughness; however, it may substantially indicate probable toughness in weldments under suitable restrictions of application. Minimum requirements for such an approximation are as follows:

1. Reliable correlation has to be established between welding heat input rates and hardness traverse patterns across the weld HAZ.

2. There should be a similar correlation between toughness and hardness at all points in such a HAZ traverse.

The most difficult accomplishment is to get Charpy test specimens which have uniform toughness comparable to that of each location in the weld HAZ. This has been done with highly sophisticated equipment and procedures in the Rensselaer research reported in reference 1. Based on the above concepts of the relationships between hardness and toughness, hardness traverses were made on representative sections of each test weldment and corresponding graphs plotted to exhibit HAZ hardness patterns. The significant bases of reference are indicated on these plots: (1) Base metal hardness, and (2) the weld-base metal interfaces.

The following general rules are suitable criteria for interpretation of the effects of welding exhibited by the hardness data plots:

1. Areas of the HAZ within 0.100-inch of the weld-base metal interface which exceed about 400 DPH hardness have been austenitized and quenched rapidly, and are approximately 100 percent untempered martensite.

2. Areas in the above described location with hardness levels between 400 DPH and the upper limit of the base metal hardness range are martensite, formed as described above, but tempered by the heat of subsequent welding.

3. Areas of the HAZ more than 0.100-inch from the weld-base metal interface which exhibit hardness below the lower limit of base-metal hardness are overtempered base metal.

4. Untempered martensite is undesirable because it has lowered toughness and acts as a stress raiser because of low ductility.

5. Overtempered zones exhibiting hardness less than 10 percent below the average base metal hardness have sharply reduced toughness, which decreases very rapidly with further decreases in hardness. Overtempering reduces the percentage of martensite present in the structure,

thus eliminating the microstructure upon which toughness depends. Concurrent drop in hardness is an indicator but not a proportional measure of the loss in toughness.

The unique contribution of the hardness plots, as an interpretation criterion for these weldments, is that of providing an essentially continuous and precise record of change throughout the critical HAZ. Hardness levels and distribution, related to the weld-base metal interface and to the original base metal hardness, provides vital reference orientation. Reliably established correlations between hardness, thermal effects, and microstructure, utilized as hardness plot interpretation criteria, provide extremely useful means for appraisal of both welding performance and weldment integrity.

No predominant hardness pattern exists for these test weldments as evidenced by the wide variations displayed by the hardness plots.

<u>Results pertaining to specific program objectives</u>. - A summary of average results for all test weldments is presented in Table II. This tabulation reemphasized that program objectives were largely concerned with evaluating the steel manufacturer's thermal control recommendations by employing insufficient, as well as excessive, heat input rates which may also approximate production malpractices.

<u>Heat input rates</u>. - The effects of heat input rate during welding can be interpreted to a degree by means of hardness evaluation. Analysis of the hardness plots disclosed that the effect of excessive welding heat has not substantially changed either the maximum or the range of hardness in the 1-inch thickness of either steel or in the 1/2-inch T-1; but the 1/2-inch T-1A exhibits both substantially higher maximum and lower minimum hardness and a great hardness spread at high heat. The extremes in hardness are exhibited predominantly in the backing weld areas and both tensile and bend failures have been shown to initiate predominantly in these areas. The majority of the backing welds were heavy deposits made with relatively high heat input rates.

Degradation of weldment integrity caused by excessive welding heat is depicted in the tests summarized in FIG 10, 11, 16, and 17. These exhibit extremely large backing welds with very low HAZ hardnesses. The tensile fractures show a generally brittle mode of failure, more evident in the backing weld HAZ of the specimens shown in FIG 16 and 17 than in those for 1-inch T-1 shown in FIG 10 and 11. This may be observed in the hardness plots as well as in the tensile test results.

There are some unique fracture relationships noted in FIG 10. The eccentricity of the backing weld is clearly evident in the photomacrograph and in the photographs of the tensile specimens. It is apparent that all tensile failures initiated in the severely overtempered HAZ. The side of the backing weld shown to have lowest hardness on the hardness plot, and the tensile failure contours all correlate with the common reference in the photomacrograph.

An excellent study of contrasts emphasizing the effects of welding heat input rates may be made by comparing the results presented in FIG 4 and 11. The photomacrograph in FIG 11 shows this weldment to have a very wide HAZ throughout the section and an excessively massive backing weld. Similar observation of the weldment presented in FIG 4 shows the opposite extreme. Maximum and minimum face weld HAZ hardnesses are comparable, but the backing weld HAZ hardness patterns are very different. The hardness range in FIG 4 is within 10 percent of base metal hardness while that of FIG 11 shows maximum hardness to be 220 DPH points above minimum hardness with these areas located about 0.140-inch apart. Contrasts in the tensile fracture appearance are nearly as great. The specimens of FIG 11 show an extremely prominent backing weld HAZ failure which clearly outlines the contour of minimum hardness. The remainder of the HAZ (closest to the weld) stands out in bold relief giving conclusive evidence of the stress raiser effect imposed by such juxtaposed microstructures, which are shown in the lower left section of the photomicrograph display of FIG 18. This figure presents the microstructure of the HAZ as related to DPH hardness. The microstructure of all samples examined corresponded with those of this figure for equivalent hardnesses. The predominance of a weld metal fracture path in FIG 11 is further testament to the stress raiser effect of an excessively overheated backing weld HAZ. The overtempered zone obviously failed until it terminated in the weld metal near the weld centerline.

T-1 versus T-1A and 1-inch versus 1/2-inch plate thickness. - The interdependence of steel grade and plate thickness with thermal effects of welding demands that they be evaluated accordingly. The differences between these steels, of significance in welding, pivot about the relative hardenability. The difference in hardenability is caused by the variation in alloy content. Comparisons of 1-inch T-1 and T-1A in FIG 11 and 13, respectively, show the increased overtempering response of T-1A. The excessively low hardness values shown in the left HAZ of FIG 11 shows the influence of the excessively heavy root passes, as compared to the values shown in the FIG 13 weld. Though not assessed quantitatively, these root weld contours indicate that the welding heat input in the FIG 11 weldment was probably much higher than that in the FIG 13 weldment. The contrasts are more conclusive in the 1/2-inch plate weldments. Similar comparisons of FIG 14 and 15 with FIG 16 and 17 clearly exhibit T-1 steel superiority to resist softening (and loss of strength and toughness) under conditions of excessive welding heat exposure. Tensile test results corroborate the hardness evidence. No significant differences were noted between T-1 and T-1A in the 1-inch thickness, although a complete analysis was obseured by the absence of T-1A yield strength data; but the results in the 1/2-inch thickness clearly demonstrate the superior response of T-1 under more difficult conditions of welding heat control inherent in thinner plate.

U-groove versus V-groove joint design. - No advantage to weldment integrity was exhibited by either weld preparation. Evidence of greater distortion was observed in the V-groove weldments, but no failures were associated with that joint geometry. No cracking was detected in any of the weldments or in any of the cross sections examined. The generally lower mechanical properties of the 1/2-inch V-groove weldments may be related to the inherently greater thermal effects of a larger weld cross section, but this is more a function of welding procedure and performance.

CONCLUSION

A mandatory requirement for successfully welding T-1 and T-1A steels is thermal control which produces suitable cooling rates in the weld heat-affected zone. Acceptable cooling rates must be such as to avoid austenite transformation microstructures that are formed at temperatures above those producing lower bainite. For the other extreme, when untempered martensite is formed, it should be tempered, preferably by the thermal effects of subsequent weld deposits. However, the martensite of T-1 and T-1A steels is a tough, low-carbon martensite which normally can be allowed to remain in a structure without tempering with only a modest sacrifice in reliability.

Excessive overheating in the weld heat-affected zone is the more critical effect to be avoided. The mechanical properties destroyed by overtempering can be restored only by subsequent heat treatment.

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Doty, W. D.: Properties and Characteristics of a Quenched and Tempered Steel for Pressure Vessels. Welding Journal, Vol. 34, No 9, September 1955, pp 425-S 441-S.

Bibber, L. C.; Hodge, J. M.; Altman, R. C.; and Doty, W. D.: A New High-Yield-Strength Alloy Steel for Welded Structures. ASME Transactions, April 1952, pp 269-285.

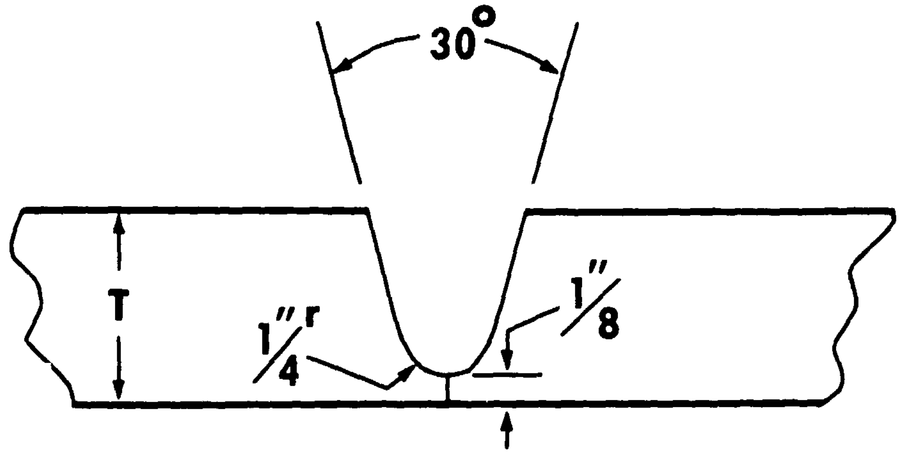
TABLE I - WELDING CONDITIONS USED IN THE STUDY

Plate Thickness	Significant Variable	T-1 Steel Low Heat Input	T-1 Steel High Heat Input	T-1A Steel Low Heat Input	T-1A Steel High Heat Input
1/2"	Electrode dia.	5/32"	5/32"	5/32"	5/32"
	Current	160-165 Amps.	160-165 Amps.	145-150 Amps.	160-165 Amps.
	Voltage	22-23 Volts	22-23 Volts	22-23 Volts	22-23 Volts
	Weld length per electrode	9 1/4"	4 1/8"	10 3/8"	6 3/8"
	Welding speed	8 i.p.m.	3 3/4 i.p.m.	9 i.p.m.	5 1/2 i.p.m.
	Heat input Rate, joules/in.	27,500	58,500	22,000	40,000
	% of maximum recommended heat*	58.5%	125%	69%	125%
1"	Electrode dia.	5/32"	3/16"	5/32"	3/16"
	Current	16-165 Amps.	225-230 Amps.	160-165 Amps.	225-230 Amps.
	Voltage	22-23 Volts	22-23- Volts	22-23 Volts	22-23 Volts
	Weld length per electrode	9 1/4"	2 1/4"	9 1/4"	3 1/4"
	Welding speed	8 i.p.m.	2 i.p.m.	8 i.p.m.	2 7/8 i.p.m.
	Heat input rate, joules/in.	27,500	153,500	27,500	108,500
	% of maximum recommended heat*	22%	122%	32%	126 %

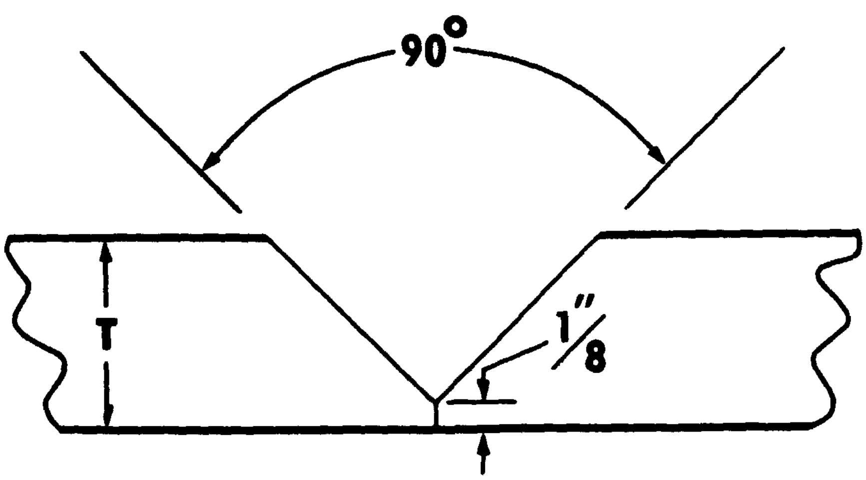
*Maximum recommended heat in kilo - joules per inch by the manufacture of T-1 and T-1A steels

TABLE II. - SUMMARY OF EVALUATION CRITERIA AND RESULTS VERSUS WELDING HEAT INPUT

Heat Input Joules/In 1000	Nominal % of Maximum Recommended Welding Heat Input Rate	Steel Thickness And Grade	Average Tensile Properties				Bend Angle to Initiate Fracture	
			Ultimate Strength ksi	Yield Strength (0.2% Offset) ksi	Yield to Ultimate Strength Ratio	Elongation % in 2 Inches	% of Specimens Tested	Average Angle
27.5	22	1" T-1	117	95	0.81	16.7	50	125°
							50	60°
27.5	32	1" T-1A	119.7	106.5	0.89	14.2	38	120°
							62	60°
27.5	58.5	1/2" T-1	123	100.4	0.82	9.4	25	150°
							75	55°
22.0	69	1/2" T-1A	122.4	102.8	0.84	12.6	38	150°
							62	65°
153.5	122	1" T-1	119.7	94.5	0.79	17.9	13	150°
							87	70°
108.5	125	1" T-1A	112.4	Not Obtained	-	12.5	100	60°
58.5	126	1/2" T-1	121	93.5	0.77	13.9	50	155°
							50	45°
40.0	125	1/2" T-1A	109.8	77.9	0.71	12.9	62	160°
							38	65°

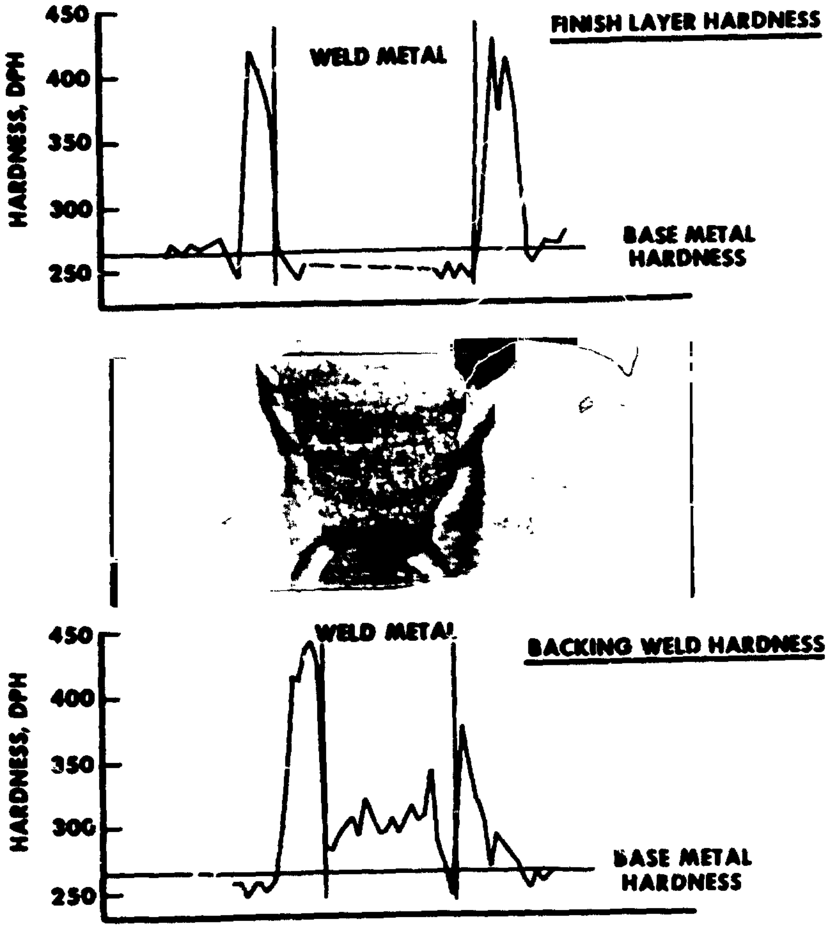


"U" GROOVE

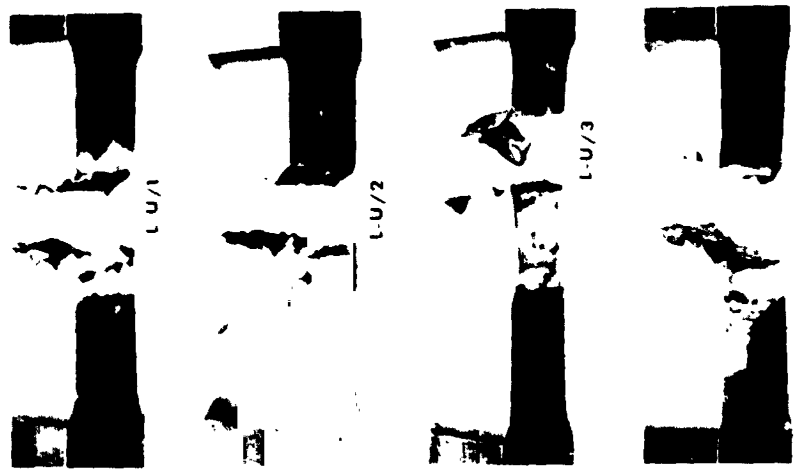


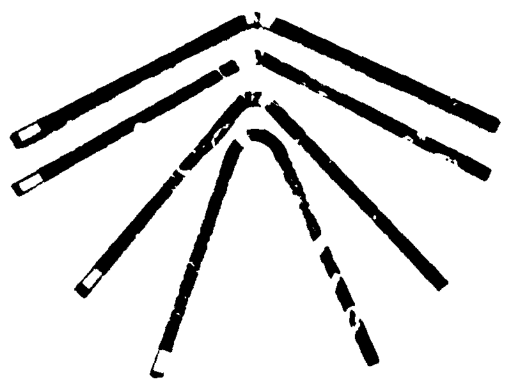
"V" GROOVE

FIGURE 1. - JOINT DESIGNS USED IN EVALUATION OF T-1 AND T-1A WELDS



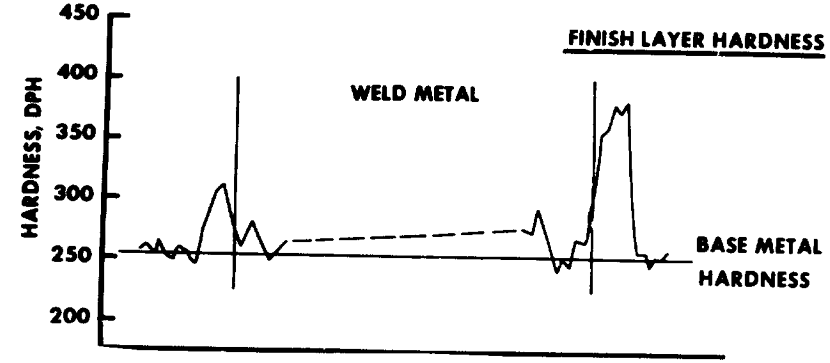
HEAT INPUT RATE 22% OF RECOMMENDED MAXIMUM

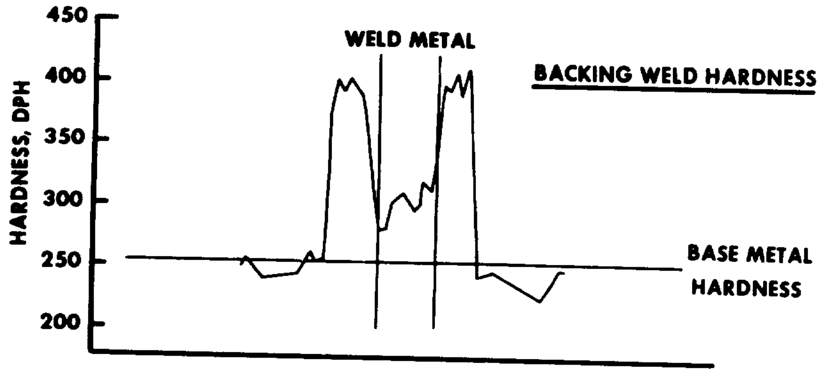




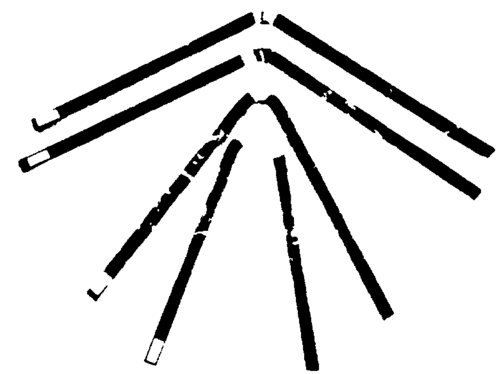
TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S., KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	115.4	93.8	10.0	95°
2	117.4	96.3	18.0	140°
3	118.6	96.5	17.0	60°
4	115.8	102.1	11.5	55°

FIGURE 2. - TEST RESULTS ON 1-INCH T-1 STEEL PLATE WELDED USING A HEAT INPUT RATE OF 27,500 JOULES/INCH. ("U" GROOVE)



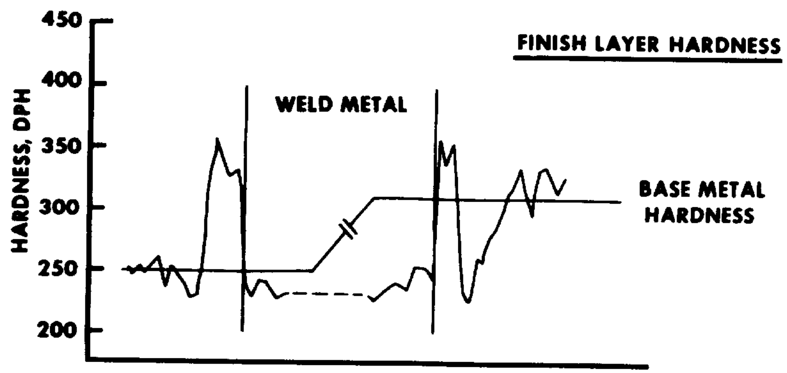


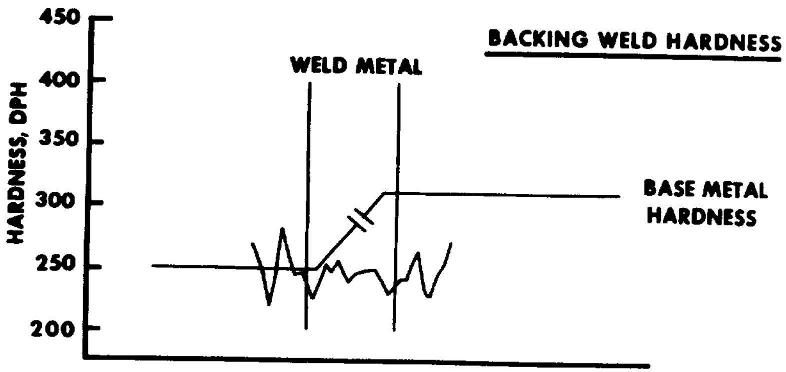
HEAT INPUT RATE 22% OF RECOMMENDED MAXIMUM



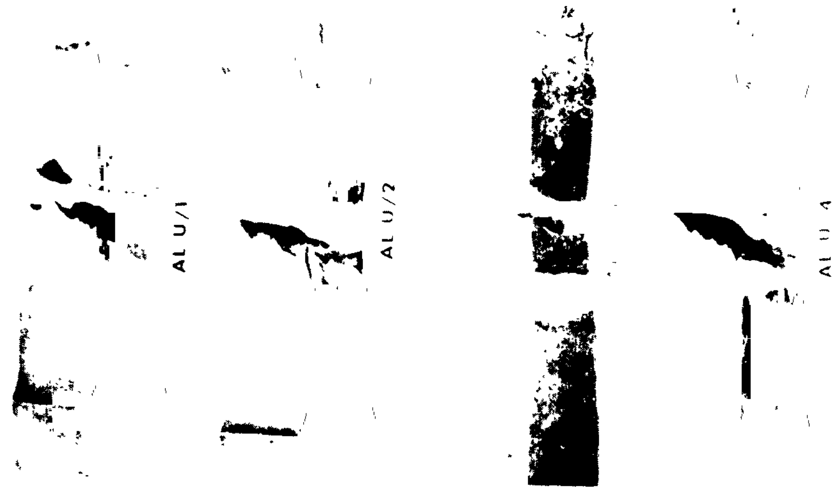
NO.	TENSILE PROPERTIES U.T.S., KSI	Y.S., KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	115.6	94.6	17.0	115°
2	116.7	90.6	22.0	150°
3	117.4	94.9	19.0	60°
4	118.7	91.1	–	60°

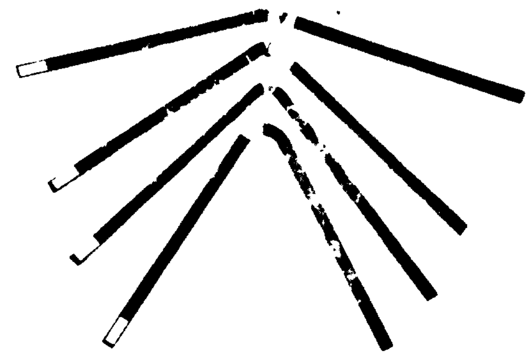
FIGURE 3. - TEST RESULTS ON 1-INCH T-1 STEEL PLATE WELDED USING A HEAT INPUT RATE OF 27,500 JOULES/INCH. ("V" GROOVE)





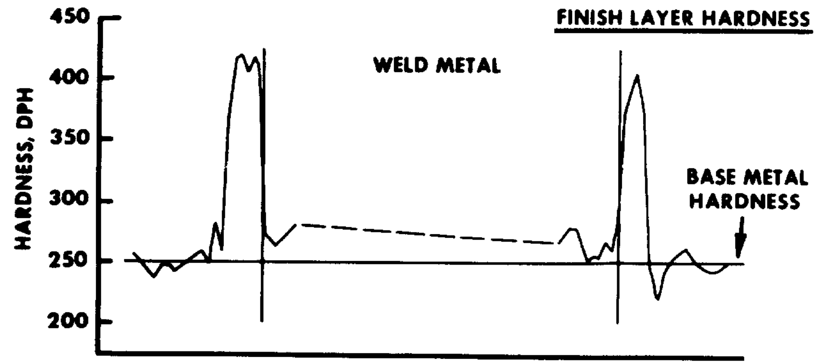
HEAT INPUT RATE 32% OF RECOMMENDED MAXIMUM

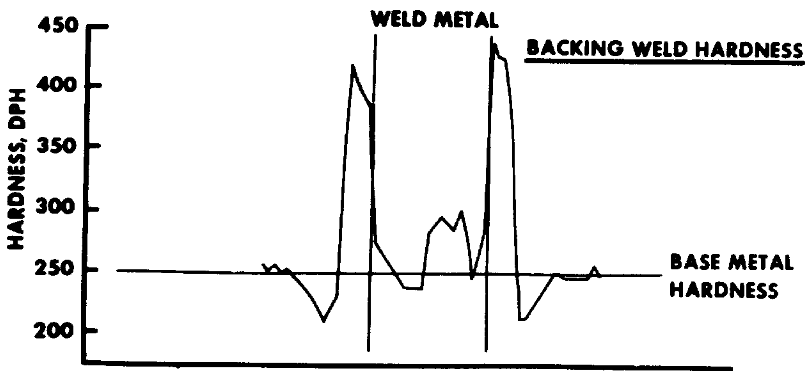




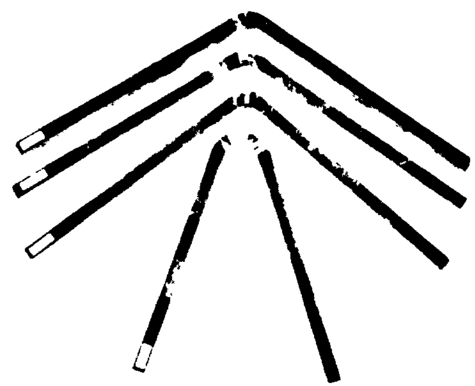
TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S.,KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	120.1	110.1	9.0	95°
2	120.6	108.8	11.0	30°
3	118.7	105.1	13.0	120°
4	121.3	109.2	13.5	75°

FIGURE 4. - TEST RESULTS ON 1-INCH T-1A STEEL PLATE WELDED USING A HEAT INPUT RATE OF 27,500 JOULES/INCH. ("U" GROOVE)



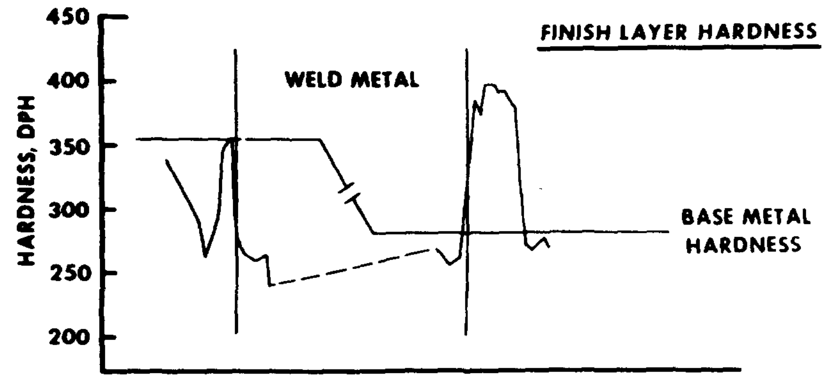


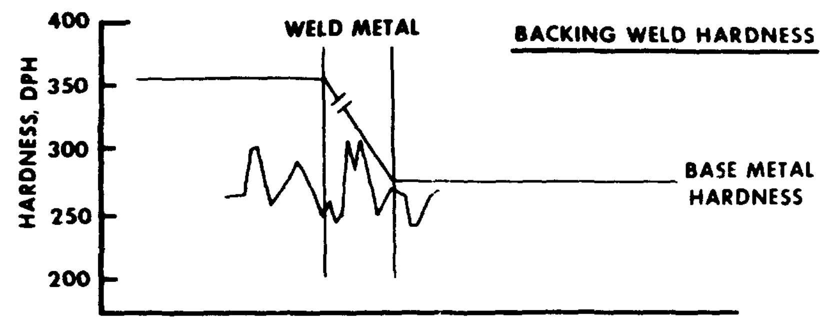
HEAT INPUT RATE 32% OF RECOMMENDED MAXIMUM



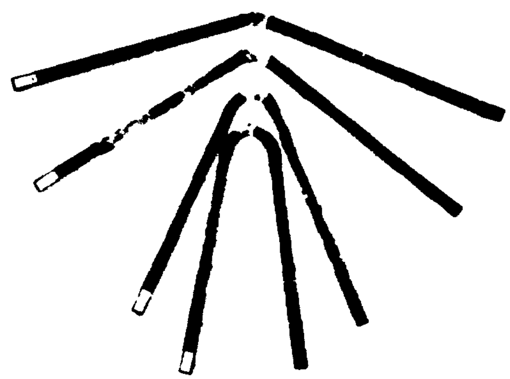
NO.	TENSILE PROPERTIES U.T.S., KSI	Y.S.,KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	123.1	–	18.0	145°
2	121.0	106.8	14.5	75°
3	118.8	104.8	17.5	65°
4	117.6	102.3	17.0	65°

FIGURE 5. - TEST RESULTS ON 1-INCH T-1A STEEL PLATE WELDED USING A HEAT INPUT RATE OF 27,500 JOULES/INCH. ("V" GROOVE)



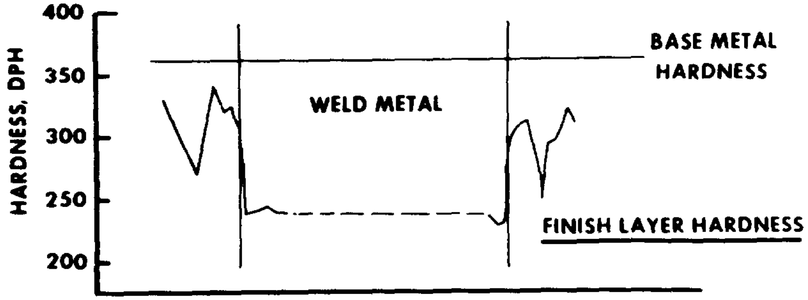


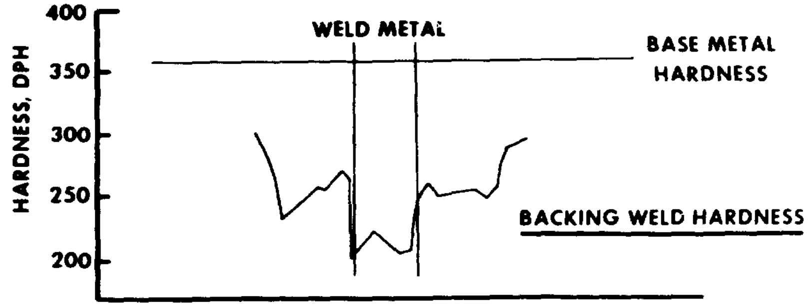
HEAT INPUT RATE 58.5% OF RECOMMENDED MAXIMUM



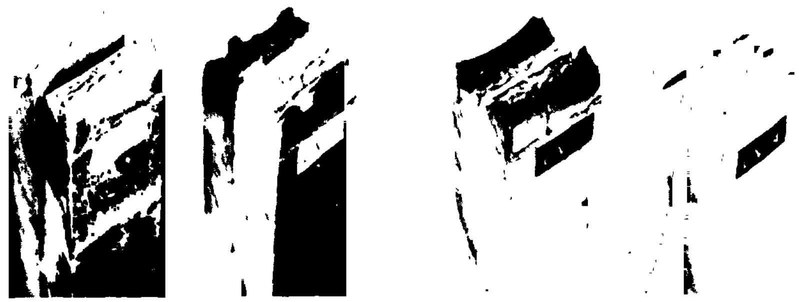
TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S.,KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	130.9	106.5	10.5	165°
2	131.9	110.5	5.0	130°
3	138.5	105.7	8.0	80°
4	131.0	108.2	9.0	30°

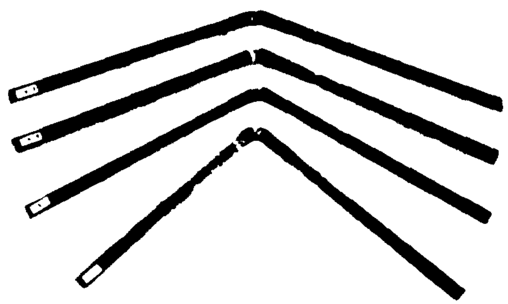
FIGURE 6. - TEST RESULTS ON ½-INCH T-1 STEEL PLATE WELDED USING A HEAT INPUT RATE OF 27,500 JOULES/INCH. ("U" GROOVE)





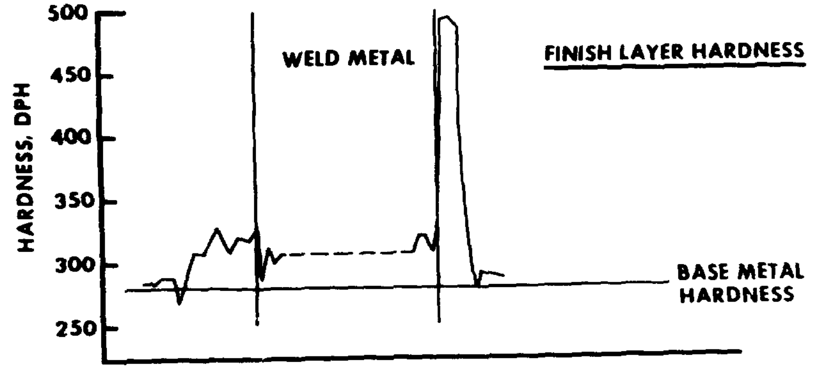
HEAT INPUT RATE 58.5% OF RECOMMENDED MAXIMUM

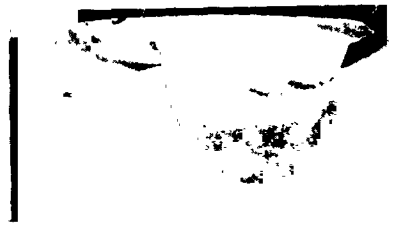


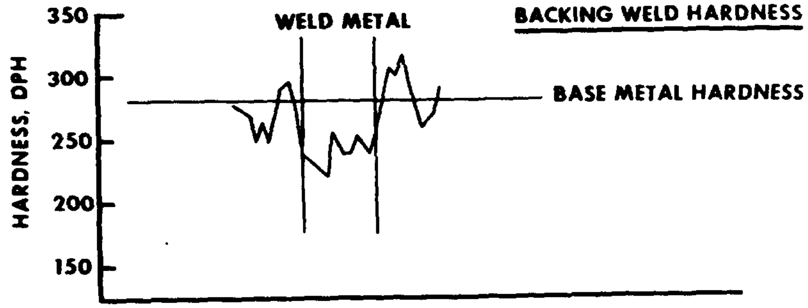


TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S., KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	116.3	95.7	10.0	55°
2	107.4	91.2	6.5	40°
3	103.7	92.0	9.5	80°
4	117.1	94.2	9.0	45°

FIGURE 7. - TEST RESULTS ON ½-INCH T-1 STEEL PLATE WELDED USING A HEAT INPUT RATE OF 27,500 JOULES/INCH. ("V" GROOVE)



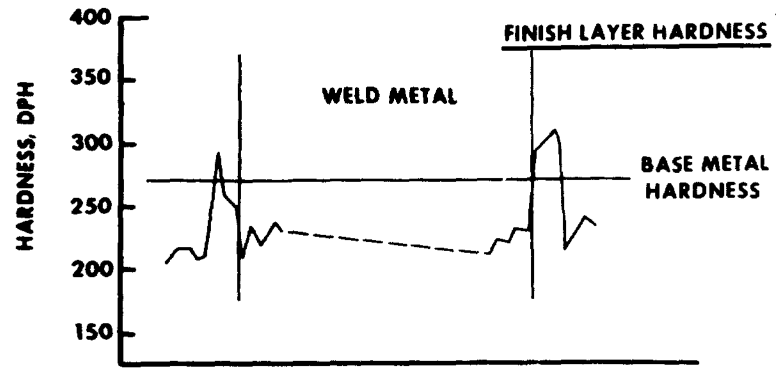


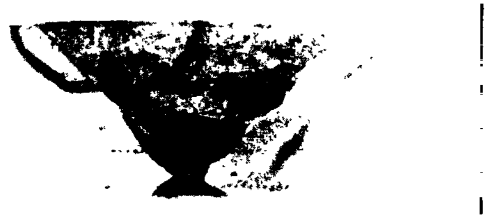


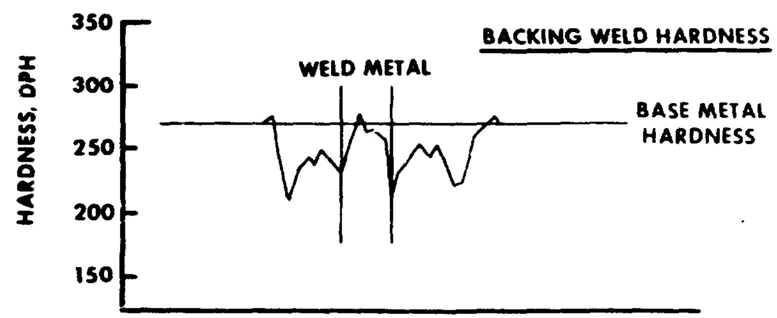
NO.	TENSILE PROPERTIES U.T.S., KSI	Y.S.,KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	120.9	100.9	9.0	60°
2	131.0	103.8	11.5	75°
3	128.6	105.9	11.5	50°
4	120.9	108.0	10.0	70°

HEAT INPUT RATE 69% OF RECOMMENDED MAXIMUM

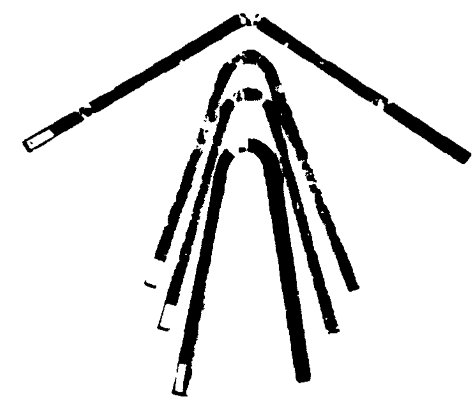
FIGURE 8. - TEST RESULTS ON ½-INCH T-1A STEEL PLATE WELDED USING A HEAT INPUT RATE OF 22,000 JOULES/INCH. ("U" GROOVE)





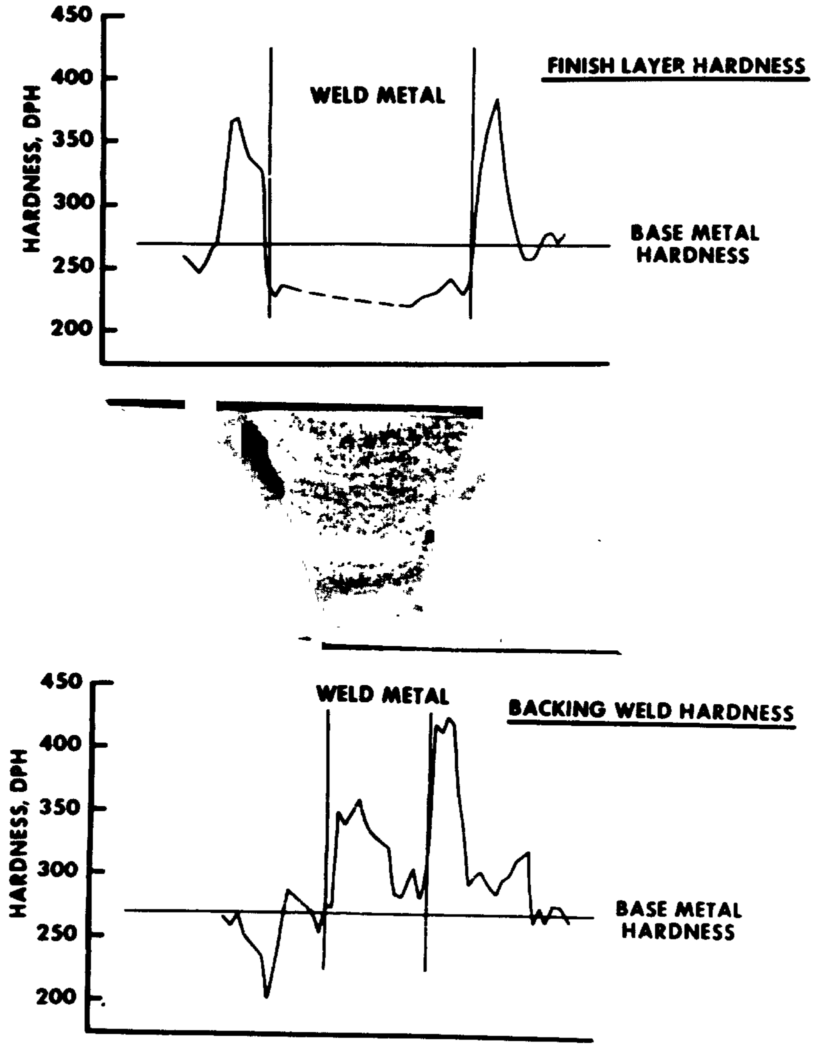


HEAT INPUT RATE 69% OF RECOMMENDED MAXIMUM

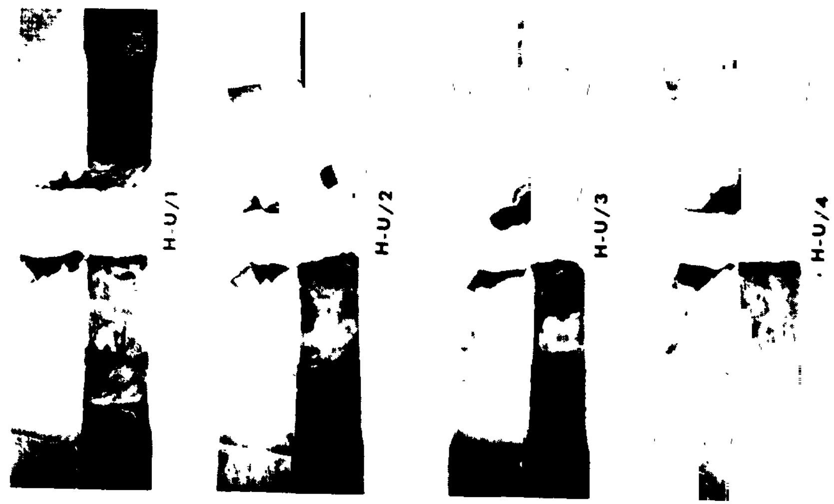


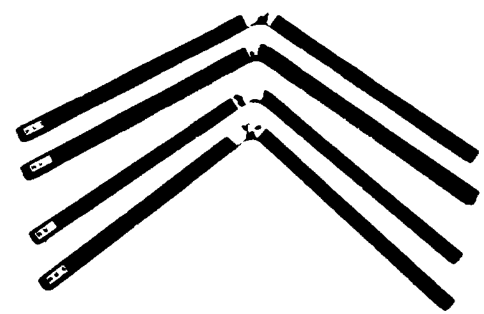
TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S.,KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	117.0	99.7	12.5	150°
2	118.2	–	7.5	65°
3	118.6	98.3	19.0	160°
4	120.0	102.7	15.0	140°

FIGURE 9. - TEST RESULTS ON ½-INCH T-1A STEEL PLATE WELDED USING A HEAT INPUT RATE OF 22,000 JOULES/INCH. ("V" GROOVE)



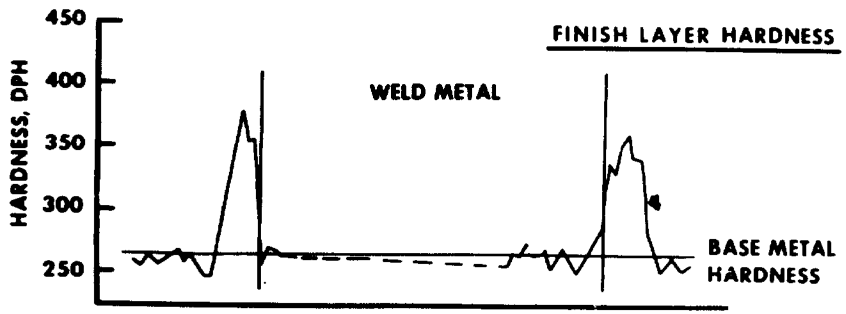
HEAT INPUT RATE 122% OF RECOMMENDED MAXIMUM

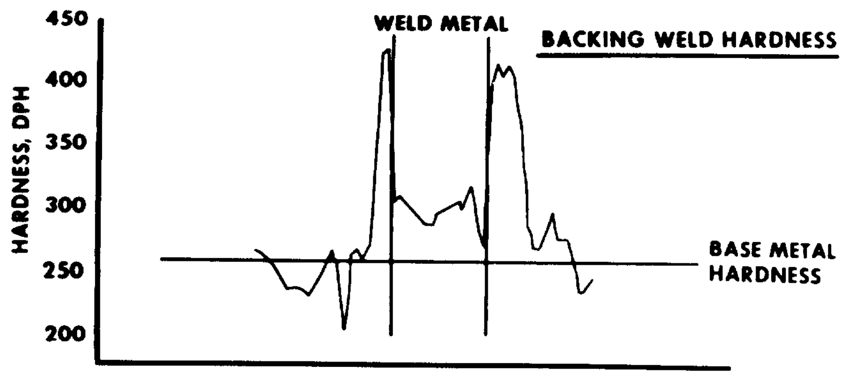




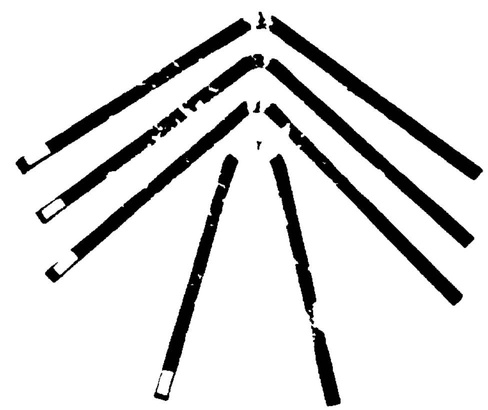
TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S., KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	117.8	96.9	11.0	60°
2	120.5	92.0	15.0	80°
3	116.2	—	12.5	75°
4	117.2	93.2	14.5	65°

FIGURE 10. - TEST RESULTS ON 1-INCH T-1 STEEL PLATE WELDED USING A HEAT INPUT RATE OF 153,500 JOULES/INCH. ("U" GROOVE)



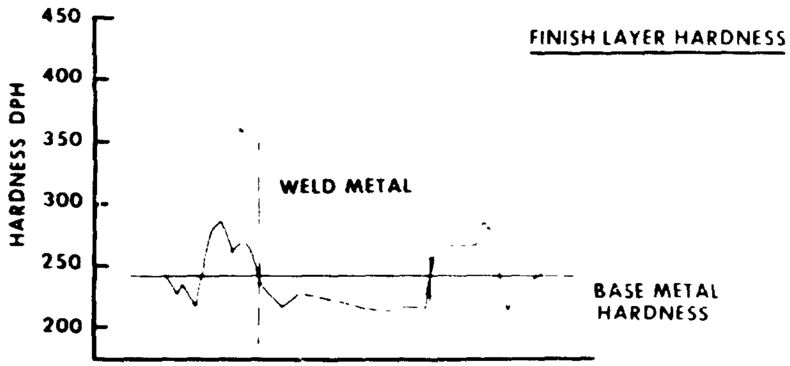


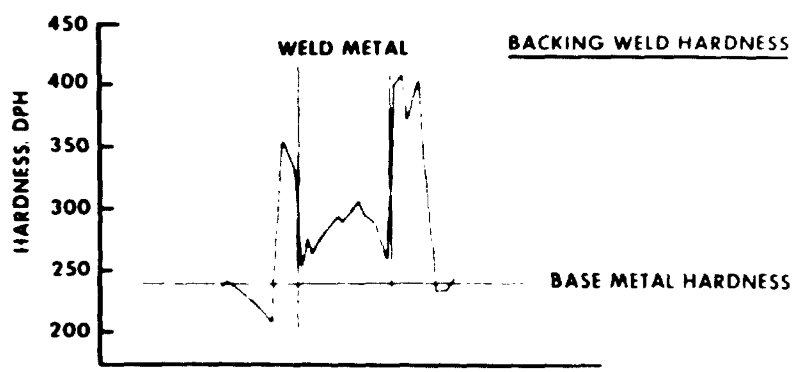
HEAT INPUT RATE 122% OF RECOMMENDED MAXIMUM



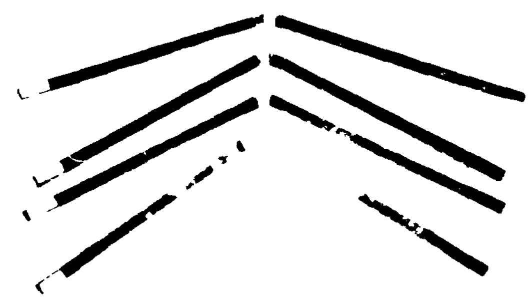
TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S.,KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	121.5	96.0	23.0	150°
2	120.5	94.3	23.5	85°
3	121.4	97.8	21.5	70°
4	122.3	92.0	21.5	80°

FIGURE 11. - TEST RESULTS ON 1-INCH T-1 STEEL PLATE WELDED USING A HEAT INPUT RATE OF 153,500 JOULES/INCH. ("V" GROOVE)



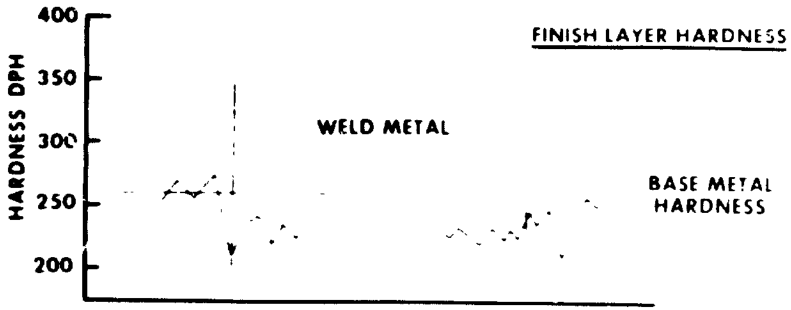


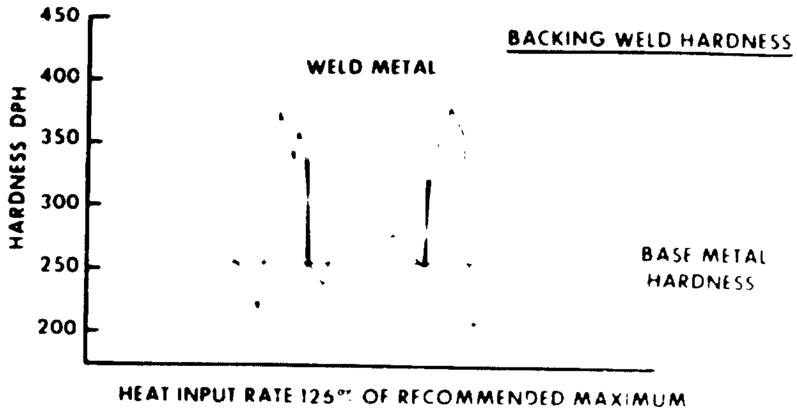
HEAT INPUT RATE 126% OF RECOMMENDED MAXIMUM

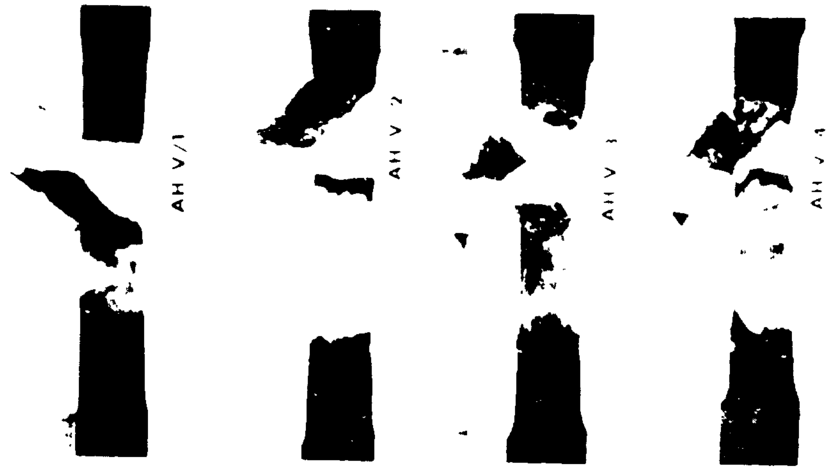


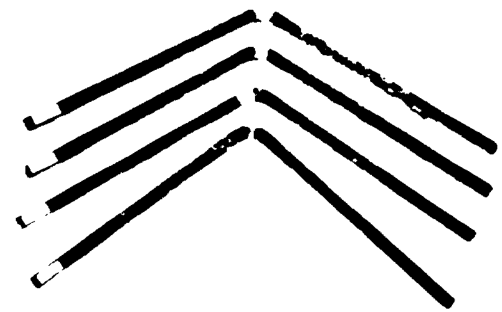
TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S.,KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	111.0	—	11.0	70°
2	113.6	—	10.0	35°
3	110.0	—	13.5	55°
4	112.0	—	15.0	50°

FIGURE 12. - TEST RESULTS ON 1-INCH T-1A STEEL PLATE WELDED USING A HEAT INPUT RATE OF 108,500 JOULES/INCH ("U" GROOVE)



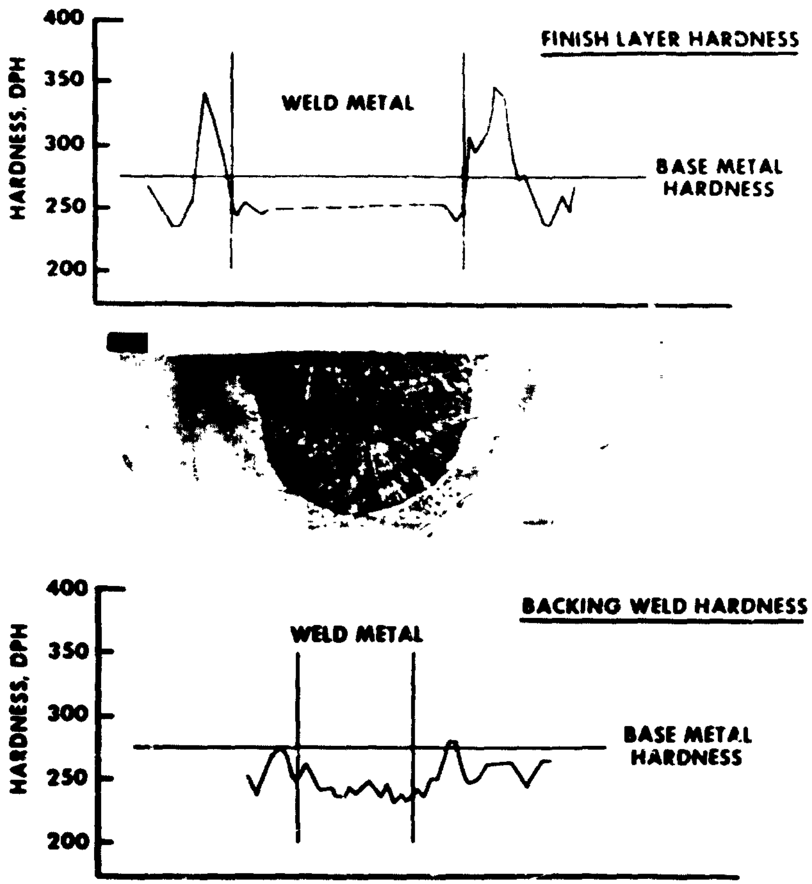


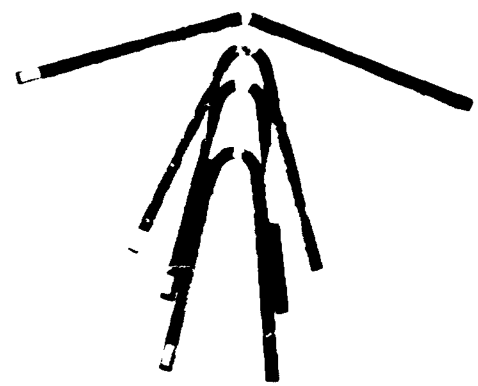




TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S.,KSI	% ELONG. IN 2 IN.	BEND ANGLE
1	114 8	—	11 5	65°
2	112 3	—	11 5	55°
3	114 5	—	13 0	60
4	110 3	—	14 0	80°

FIGURE 13 - TEST RESULTS ON 1-INCH T-1A STEEL PLATE WELDED USING A HEAT INPUT RATE OF 108,500 JOULES/INCH (V GROOVE)





HEAT INPUT RATE 125% OF RECOMMENDED MAXIMUM

TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S.,KSI (0 2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	125.0	98.0	15.0	160°
2	124.5	92.8	16.0	160°
3	123.1	95.1	15.0	140°
4	112.8	94.9	8.5	45°

FIGURE 14. - TEST RESULTS ON ½-INCH T-1 STEEL PLATE WELDED USING A HEAT INPUT RATE OF 58,500 JOULES/INCH. ("U" GROOVE)

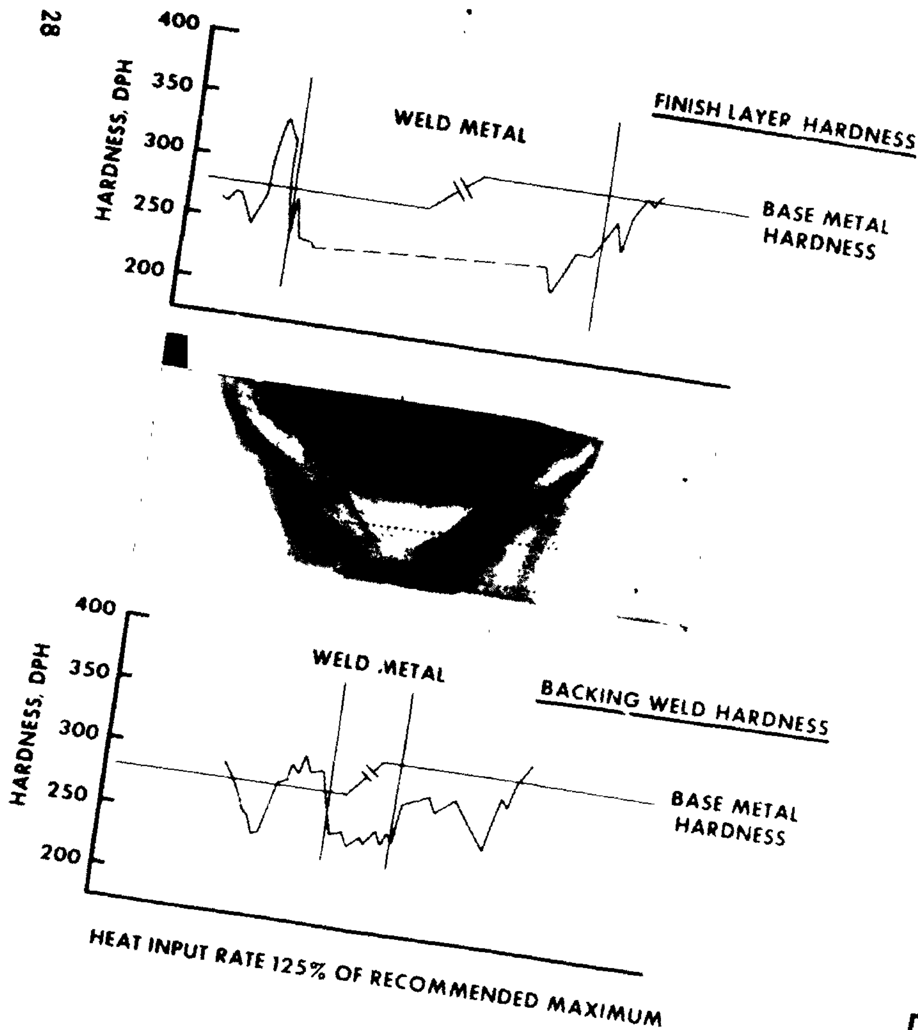
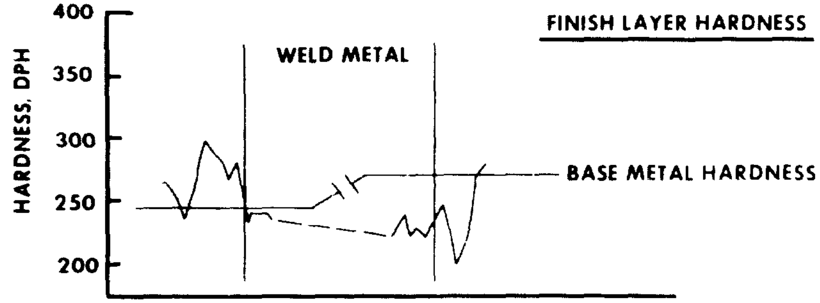
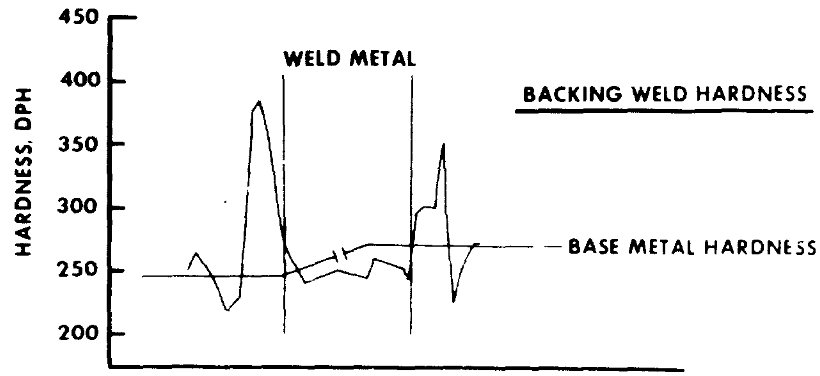


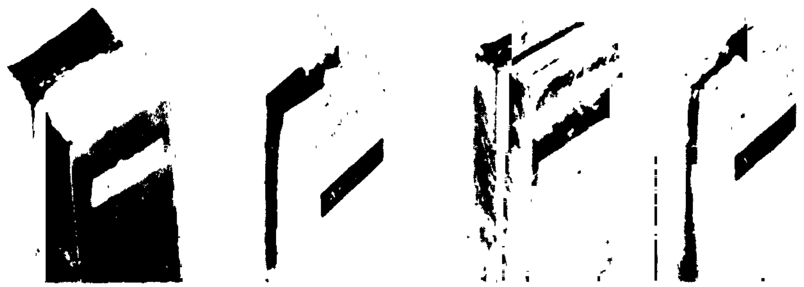
FIGURE 15. - TEST RESULTS ON ½-INCH T-1 STEEL PLATE WELDED USING A HEAT INPUT RATE OF 58.500 JOULES/INCH ("V" GROOVE)

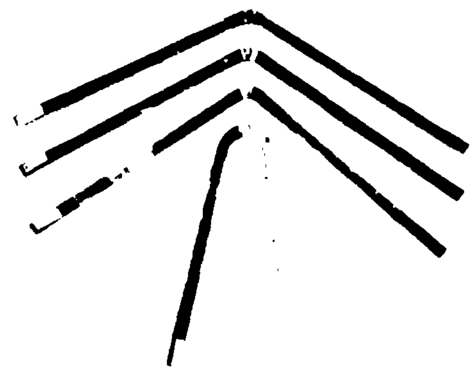
NO.	TENSILE PROPERTIES U.T.S., KSI	Y.S., KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	116.4	91.7	10.5	15°
2	117.0	86.9	16.0	70°
3	119.9	92.4	12.0	165°
4	117.5	95.5	11.5	55°





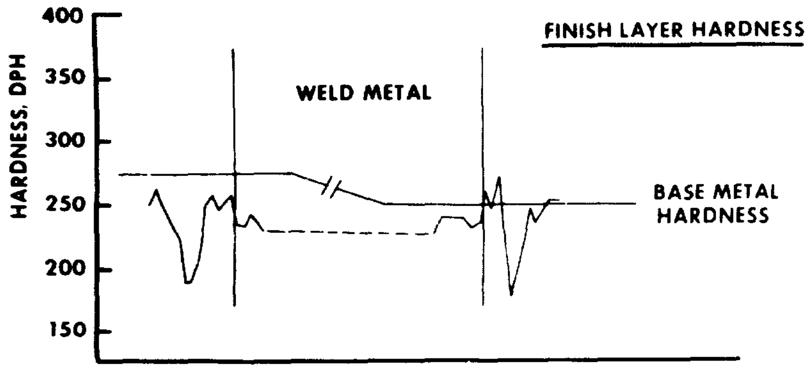
HEAT INPUT RATE 125% OF RECOMMENDED MAXIMUM

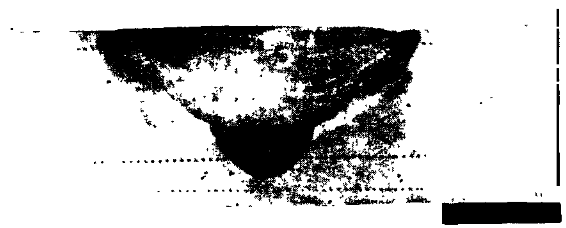


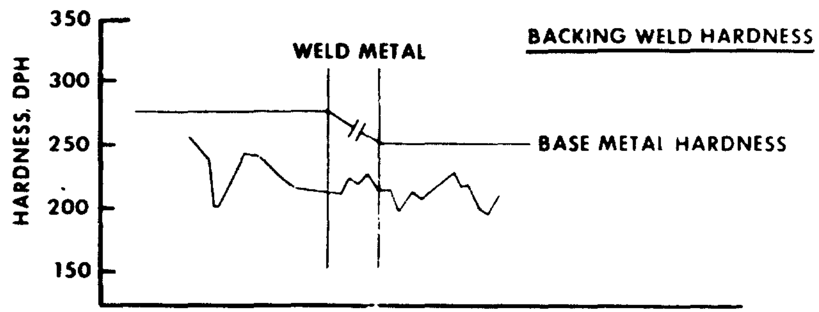


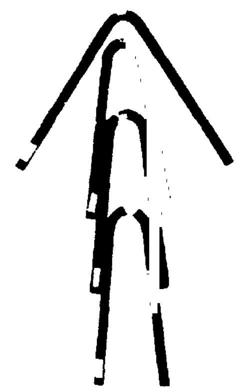
NO.	TENSILE PROPERTIES U.T.S., KSI	Y.S., KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	117.0	72.0	11.0	60°
2	111.3	72.7	11.0	165°
3	112.0	73.9	7.0	60°
4	113.0	72.3	8.0	75°

FIGURE 16. - TEST RESULTS ON ½-INCH T-1A STEEL PLATE WELDED USING A HEAT INPUT RATE OF 40,000 JOULES/INCH ("U" GROOVE)









TENSILE PROPERTIES				
NO.	U.T.S., KSI	Y.S.,KSI (0.2% OFFSET)	% ELONG. IN 2 IN.	BEND ANGLE
1	106.3	83.5	15.0	170°
2	105.0	81.9	18.0	170°
3	106.6	85.2	18.0	125°
4	106.7	81.2	15.0	165°

HEAT INPUT RATE 125% OF RECOMMENDED MAXIMUM

FIGURE 17 - TEST RESULTS ON ½-INCH T-1A STEEL PLATE WELDED USING A HEAT INPUT RATE OF 40,000 JOULES/INCH. ("V" GROOVE)

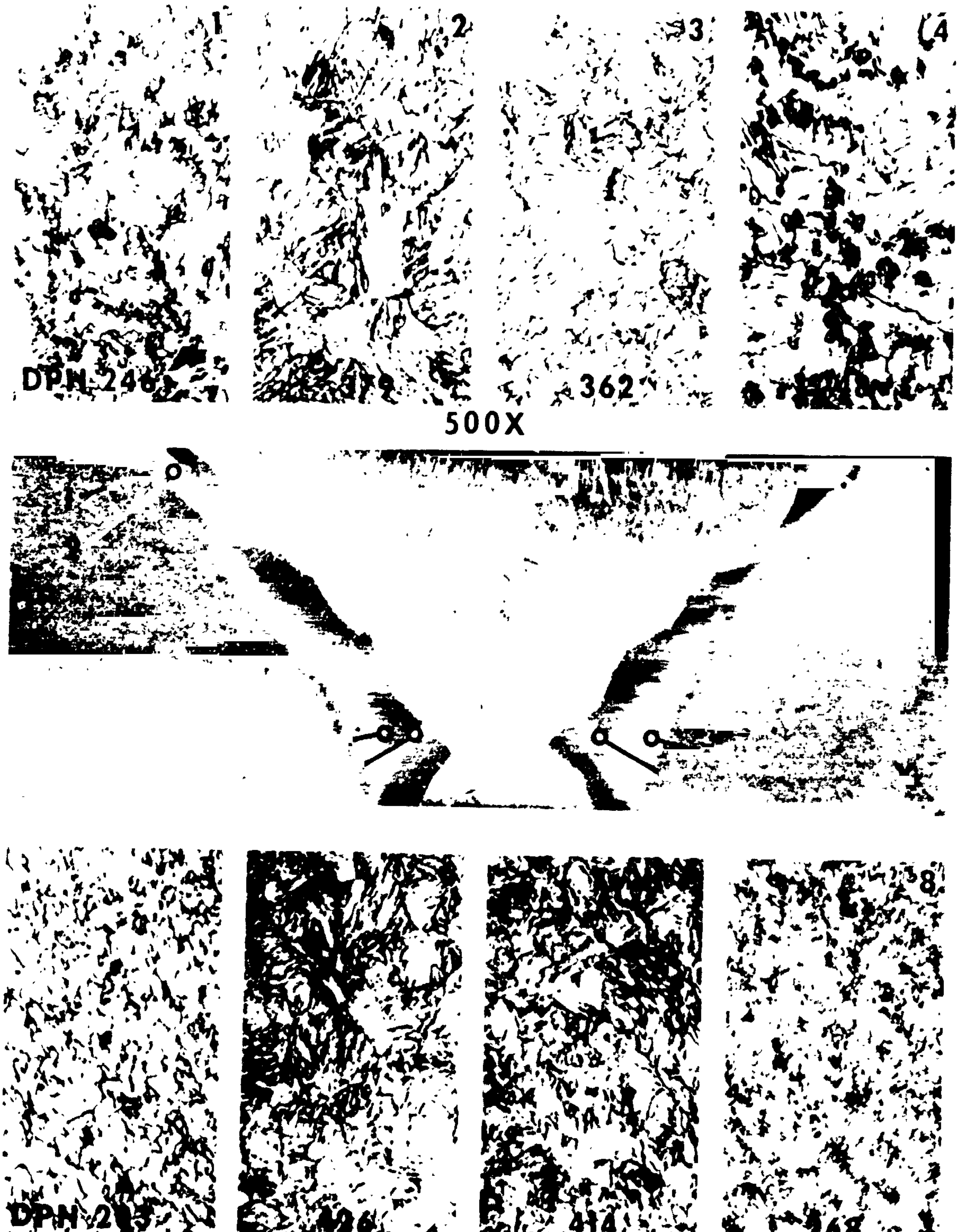


FIGURE 18. - MICROSTRUCTURE AND DPH HARDNESS AS RELATED TO LOCATION IN THE HEAT AFFECTED ZONE

November 14, 1966 APPROVAL NASA TM X-53537

A STUDY ON THE EFFECTS OF VARIOUS HEAT INPUT RATES ON T-1 AND T-1A STEEL WELDS

By M. G. Olsen, R. A. Davis, and S. W. Worden

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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